Cognitive prostheses : findings from attempts to model some aspects of cognition

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Abstract - Improvements in the power and portability of computing systems have made possible the field of cognitive prostheses, which attempts to make up for cognitive impairment by to some degree modeling cognitive processes in software. Research on interfacing directly with the brain is at a very early stage. However, in research into dementia care, a number of non-invasive research prototypes have been developed to support people with dementia in specific areas of functioning, such as carrying out everyday activities, holding a conversation, being entertained, and being creative. Findings from the individual projects which may have general applicability are highlighted.

Keywords : Cognitive prostheses, assistive technology, dementia

1 Internal and External Cognitive Prostheses

Cognitive impairment can be from congenital or developmental causes, or can arise from illness or injury. This creates difficulties for the person in coping with everyday life. Improvements in the power and portability of computing systems have led to the development of the field of cognitive prostheses, which attempts to make up for cognitive impairment by to some degree modeling cognitive processes in software.

Developing systems which can interface directly with the brain is at a very early stage. Cochlear implants have been developed to replace the function of the cochlea for profoundly deaf people. Although the results are much cruder than a sound signal processed in the normal way, they do represent a successfully working physical interface between technology and nerve cells [1]. Attempts are being made to similarly develop a range of implants which can restore cognitive function to

individuals with brain tissue loss due to injury, disease, or stroke by performing the function of the damaged tissue with integrated circuits. An example of current work is developing a prosthetic for the treatment of hippocampus damage, including that caused by Alzheimer's disease [2]. An implant is currently being tested in rats.

Having implanted cognitive prostheses may be quite a long way off, but it may be possible to provide a significant amount of help for people with cognitive deficits by focussing on the activities which their impairment is affecting, and developing external systems which prompt and support them through these specific activities. In this way a system can to some degree take over cognitive functions that a person is having problems with.

One inspiration for this work is the realisation that many computer applications which assist all of us in our daily tasks could actually be considered extensions of our cognitive processes. This includes the cognitive assistance offered to us by pocket calculators, spreadsheets, and financial decision support systems.

An example of people with cognitive difficulties who can benefit from computers without any specialist software is people with learning difficulties. In many cases a standard word processor provides better motivation and better access to writing than a pen and paper. The result is always neat and mistakes can be undone very easily. Computers can make the text in emails, documents and web pages more accessible through the use of text-to-speech. Creating multimedia using modern computers is becoming increasingly easier. It can allow people with cognitive difficulties to bring together video, pictures, sounds and symbols into a single package that communicates their needs, wishes or achievements [3].

The use of computers in this way relates to another new field of enquiry : distributed cognition. Distributed cognition is a psychological theory incorporating findings from sociology and cognitive science. It is a study that makes clear the deep inter-relationship between individuals, artefacts and the environment. Distributed cognition sees human knowledge and cognition as not being confined to the individual. Instead, it is distributed by placing memories, facts, or knowledge on the objects, individuals, and tools in our environment [4]. As Salomon put it, "People think in conjunction and partnership with others and with the help of culturally provided tools and implements" [5].

2 Dementia

Cognitive deficits can be produced by a variety of causes, but by far the most widespread and rapidly growing cause of this problem is dementia in older people. Dementia is the loss of cognitive abilities, particularly the use of working (short-term) memory, usually as a result of Alzheimer's disease or stroke. Dementia occurs

primarily in older people, and while it does not affect all of them, its rate of occurrence rises steeply from about 1 in 5 of people in their 80s to 1 in 3 of those in their 90s [6,7]. As the world's population balance shifts towards the older end of the spectrum, the incidence of dementia will continue to increase [8]. The effects of dementia can be quite devastating for the person and their family, and pose significant challenges to professional carers. There is currently no way to stop or reverse the physical causes of dementia. Until such help is found, there will be a need to develop social and technological supports for people with dementia and their carers. This paper outlines a number of research projects with this aim.

2.1 Daily Activities

People with dementia find it increasingly difficult to carry out daily activities, which puts a great strain on family carers, and eventually can result in referral to residential care. Most people with dementia, and their families, prefer that they remain in their own homes as long as possible. Work is ongoing to find ways in which technology could assist by providing appropriate and acceptable support to relieve some of the burden on carers.

The Institute for Cognitive Prosthetics in Pennsylvania, USA, has been working for twenty years on developing ways to support people with cognitive difficulties in daily activities through technology [9].

The group has found that cognitive assistive technology requires substantial customization for each patient, and that there are islands of deficits in seas of ability and vice versa. Activities that are objectively simple can be complex for the user, but encouragingly, brain plasticity has been seen as a result of intensive use of cognitive prostheses. Also cognitively impaired patients will develop creative unanticipated uses for new systems. And, to put technology in its proper place, just because a computer can perform a task more accurately doesn't mean that the patient should not be allowed the satisfaction of performing the task on their own.

A system under development at the University of Toronto aims to develop non-invasive ways of monitoring the activities of a person with dementia in their home, in order to deliver timely and relevant prompts to help them with daily activities [10]. The system uses computer vision and so does not need any equipment attached to the person. This of course makes it more difficult to interpret what is happening and a great deal of computational intelligence is employed. The person's movements must be tracked, and then a determination made of what they are attempting to do. Then a decision must be made as to how best to prompt them. For tracking, the system makes use of a Bayesian system, which is a way of calculating probabilities based on developing knowledge gained. It then uses a Markov process to decide what the user is doing and how to prompt them. As well as its possible practical applications, this

work represents an interesting contribution both to computer vision modeling of human activities and decision making under uncertainty.

The first task the project has tackled is hand washing in the bathroom. The initial results have been successful. Further work for the team will include trying to find ways to assist with tooth brushing and then the far more challenging task of helping with using the toilet. Other technologies to be considered are using sound as well as visual input (e.g. whether the water is running), and speech recognition to detect what the user is saying during the process.

A prototype comprehensive home support system for people with dementia has been developed through a European funded collaboration [11]. The aim of the project was to develop a touchscreen based support system which collated sensor information from around the house and assisted the user by supplying a wide range of prompts and supports, including a daily agenda, pop-up reminders, a locator for lost items, and step-by-step instructions for daily activities. Navigation help outdoors was provided by means of a linked handheld device. Door alarms were in place as well as automatic control of lighting and easy control of household appliances. Music and other entertainment was provided with easy to use controls.

The system performed well in tests. The team felt that particular strengths of this project were the involvement of potential users throughout the design process, and the multidisciplinary nature of the effort.

The Laboratory for Assisted Cognition Environments at Rochester University in New York is working on a number of memory and problem solving aids that help an individual perform the tasks of day-to-day life [12,13]. This interdisciplinary project combines computer science research in artificial intelligence and ubiquitous computing with clinical research on patient care.

The systems were based on multisensor (video and RFID) sequences, all of which were synchronized together. The scenarios of activities in daily living which were supported were walking around the indoor space, sitting and watching TV, preparing to use and then storing a kitchen utensil, preparing cereal, and drinking water. The experimental approach was based on calibration-free multi-view approaches which did not require cumbersome and sensitive camera calibration procedures.

At the University of York in England work has been done on assisting people with dementia to use a cooker. People with dementia have problems carrying out multi-step tasks such as are involved in cooking. Using a cooker of course carries with it significant possible risks to the safety of a person with cognitive difficulties. One problem with intelligent systems built to prompt people through a set of tasks is that the prompts used by these systems are likely to be viewed as novel. As people with dementia are known to have difficulties with novelty this could be a problem. An experiment was performed by this group to determine how to prompt people with dementia about what knob controls what burner on a cooker. A cue using a fluorescent visual path to call attention to the connection between the knob and the

hot plate was found to provide comparable or better results than more conventional alternatives. It is concluded that design in this area does not need to be constrained by the need to avoid novelty as long as the design is well carried out. The experiment is also of interest because of the way that it was embedded in a natural cooking task suitable for people of varied cognitive capacity [14].

A number of projects have experimented with using on-screen avatars to prompt the users of cognitive support systems. There have been concerns about the acceptability and the effectiveness of avatars, particularly for older users. Some work has indicated that computer-generated 3D faces can be perceived quite negatively by people with dementia, whereas traditional 2D cartoon representations can work better [15]. At the Austrian Research Centers in Vienna some recent work has involved avatars based on photographs of faces, which are then animated [16]. The assumption is that these faces will find easier acceptance than cartoon-like or less realistic avatars. The photorealistic avatars were shown to elicit a high degree of attention holding and a positive reaction from people with mild dementia.

2.2 Conversation

One of the most devastating effects of dementia is the deprivation of the ability to communicate. Without working memory, conversation becomes impossible. For many people the basic interactional structure can remain to an extent, so greetings, farewells and other forms of ritualised speech are still possible, but the rest can be repetitive or apparently meaningless to a listener. As a result people with dementia can become socially isolated and deprived of the range and variety of social interactions that characterise everyday life for unimpaired people. This can have a profound effect on the person's sense of wellbeing, and put severe strains on family and carers.

Although short-term memories are increasingly not available in dementia, longer term memories can be relatively well preserved. This is because long-term memories are stored in the brain in a different way from working memory. With dementia, the difficulty is to find a way to prompt these long term memories. This can be done by a family member who knows the person's history well, but it can be hard work, and does not make a for a relaxed and natural interchange, with both participants contributing equally.

There may be a role here for technology to provide more stimulating and complex prompting and supporting, freeing both parties to enjoy a conversation. A group at Dundee and St Andrews Universities in Scotland have developed and evaluated a system called CIRCA, which performed this role. CIRCA consisted of a hypermedia structure with reminiscence material as content, accessible via a touchscreen. The system relieved the carer or relative of the task of continually supporting the person

with dementia in a conversation. Instead they could join with them in exploring and enjoying the multimedia material, which then had the effect of regularly triggering long-term memories. The person with dementia could then relate their story or recollection [17].

The first prototype system presented the users with a choice of three reminiscence themes and three media types, drawn from approximately 10 video clips, 30 music clips, and 230 photographs. The material was chosen after consultation with about forty people with dementia and their families and carers, to determine what sort of material would be the most engaging and stimulating of conversation. Fig. 1 shows the system in use.

After an iterative development of the system, for a final formal evaluation, communicative interactions were set up between people with dementia and a carer, with and without the system being used. Since CIRCA used reminiscence contents to stimulate conversation, the control condition used standard physical reminiscence material to prompt and facilitate conversation.

Given the difficulties people with dementia may have in communicating their opinions, objective measures for such aspects of the interaction as engagement, enjoyment, and the degree to which a satisfying interaction is taking place were devised. Sessions were video recorded and then coded. A set of coding techniques was devised to describe both verbal and nonverbal behaviour that allowed focusing on (i) the people with dementia, (ii) the carers and (iii) the relationship between the two. In particular, an attempt was made to determine if people with dementia could be supported to take the lead more in conversations, rather than the contents and course of the interactions being directed by the carers. This would have a beneficial effect on the quality of life of people with dementia as the provision of a positive interaction, at whatever level a person with dementia understands it, can be considered a successful intervention [18]. In addition, facilitating staff to engage in successful reminiscence activities has been shown to have a positive impact on their attitudes towards the people they work with that continues beyond the activity sessions [19].

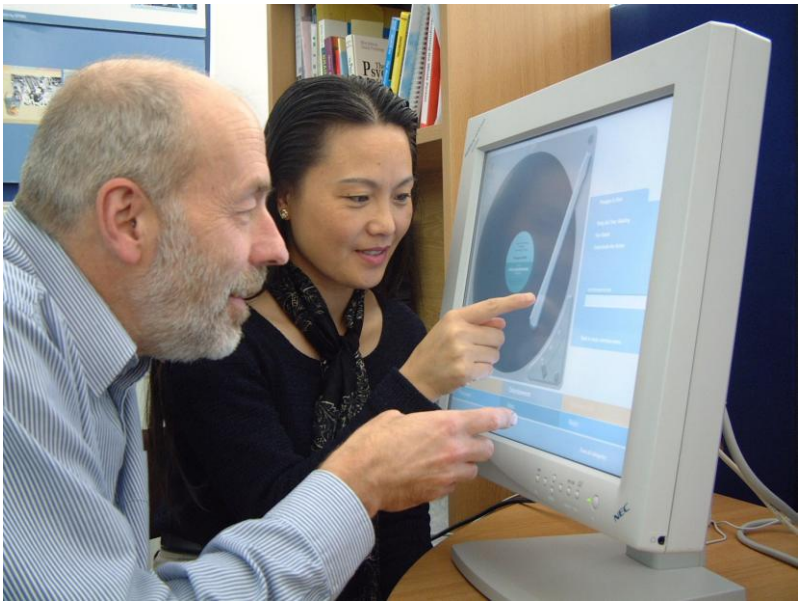

Fig. 1. The CIRCA system in use.

The CIRCA system proved successful in facilitating communication and in particular was able to give the person with dementia an increased control over the conversation, because control was shared via both participants interacting with the computer system. Staff were uniformly positive about using the system, and in some cases reported that they had learned more about the person in twenty minutes with the system than they had ever known before.

A group in Japan has developed a system which facilitated a conversation, based on reminiscence materials, which took place between a person with dementia and a family member or volunteer over the internet, thus giving support to people who might otherwise be isolated in their own homes. The system provided a two-way videophone plus the ability to easily share photographs and video clips between the participants. Trials were conducted first with people with dementia in a hospital setting, to determine if they could understand and make use of a videophone connection. Subsequent field trials of the system in more realistic settings showed that people with dementia could communicate with therapists by videophone and that the reminiscence sessions over the network were generally as successful for individuals with dementia as face-to-face reminiscence [20].

At the University of Toronto work has been done on developing multimedia reminiscence DVDs for people with dementia and their families. These were 40 minute DVD presentations made from material supplied by the family. In contrast

with the CIRCA prototype this project made use of material personal to each individual. The idea was to give them and their families a pleasant and stimulating experience, and to prompt conversation based on the person's long term memories. Responses were positive, and the long-term aim of the group is to contribute to the restoration to some degree of the 'personhood' of the individual with dementia [21,22].

2.3 Interactive Entertainment

The ability to entertain oneself is an important facet of a full life. As well as a quality of life issue, a very practical problem is that people with dementia currently need uninterrupted attention from carers all day, which can lead to exhaustion in relatives, and can make paid carers retreat from an overwhelming sense of demand into just providing the basics of physical care.

The team in Scotland who developed the CIRCA system have investigated ways in which an interactive entertainment system for people with dementia could engage them and then support and prompt them in such a way so that they would be able to use the system unaided. The first issues addressed were what sort of content for an interactive system would be appropriate and engaging for older people and what kinds of prompts would be necessary to keep the person engaged and enjoying using the system [23].

The activities developed were : games of skill, creative activities, and virtual experiences. Fig. 2 shows one of the games. The object is to get the ball past the goalie. Touching the ball launches it. Physics is taken account of, so that the ball's trajectory depends on where it is touched.

Most of the users engaged well with the activities. Much was learned about how to structure the interaction to avoid confusion or boredom. Activities with a clear and always present goal worked best. Activities which were familiar, not surprisingly, also worked well. Activities which were less successful involved occasional pauses when it was not clear what to do next, or just what was happening.

Fig. 2. A game of Beat the Goalie in the LIM system

Devising ways to replacing a helper by having the system itself prompt the user was a important part of this project. The team experimented with increasingly intrusive levels of prompting, so that the minimum level necessary to still ensure success could be determined.

Prompts could be provided, in increasing order of obtrusiveness, by :
(1) An interface which was simple and easy to figure out
(2) Visual reminders (such as an onscreen button flashing)
(3) Text boxes which could pop up with instructions or suggestions
(4) Spoken messages to the user
(5) An onscreen avatar to deliver instructions and suggestions to the user

Having tried the first four prompting methods, it was found that a well-designed interface, along with occasional text-box prompts worked well. The spoken prompts with synthetic speech did not work well. The synthetic speech was quite understandable to people without dementia, but participants with dementia simply ignored the speech, as if nothing had been said. This interesting outcome relates to work being done on difficulties older people in general and people with dementia is

particular may have with understanding synthetic speech. Visual prompts were better than verbal prompts in that they were better at keeping the initiative with the user. Users have enjoyed even the unfinished prototypes and engaged with them for extended periods without continual support from another person.

The conclusions of this project were that a successful interactive experience should have the following characteristics :

(a) An engaging, attractive and colourful interface, which promises enjoyment
(b) It is always obvious what to do next, either because of the way the interface behaves, or because of a specific prompt
(c) An element of challenge and skill mastery to the experience works well (i.e. there is a 'point' to it, even for people with little working memory)
(d) Providing continual feedback provided on the user's performance - encouragement when they are not succeeding at a task, and praise when they do succeed.

2.4 Being Creative

Looking beyond entertainment, as important as that is, a further challenge would be to devise technology which could help a person with dementia to carry out a satisfying creative activity.

A simple definition of computer-supported creativity would be an activity which is directed by the user, within limits provided by the system, which produces a result which is innovative, individual and, ideally, aesthetically pleasing.

A number of studies have shown the potential of people with dementia to be creative. Activities such as music and painting can positively influence the sense of well-being of people with dementia, with those participating showing improvements in self-esteem and mood and decreased agitation. All of these approaches have involved a great deal of planning and hard work on the part of carers to support the person with dementia in being creative. A project at Dundee University in Scotland has involved working on ways to use technology to take over some of the support needed by the person with dementia in order to carry out creative activities. A system called ExPress Play was developed to support failure-free musical composition for people with dementia. The system was intended to enable people with dementia to participate in active music making regardless of prior musical experience. Using the system always had a successful outcome. Express Play was accessed via a touch screen, and used a method of producing music which means it always sounded 'musical' [24]. Twenty-five people with dementia participated in evaluations, each taking part in three sessions spaced out over a number of days. All the sessions were videotaped. A tool was developed to continuously track and record all the selections, movements, and timings during a session, making it possible to replay the sound and display generated during each session for analysis.

Each session was intended to last ten minutes. However it was decided not to stop participants abruptly if they were deeply engaged in play, but rather stop them at the next appropriate time after ten minutes. In fact, more participants played for longer than ten minutes than expected.

A helpful feature of the system was a display of a trail of 'bubbles' that appeared as the user dragged a finger across the screen, creating the music. The bubbles faded with time so as not to fill the screen entirely, but stayed on long enough to create the effect of a visual memory of where the finger had been. See Fig. 3.

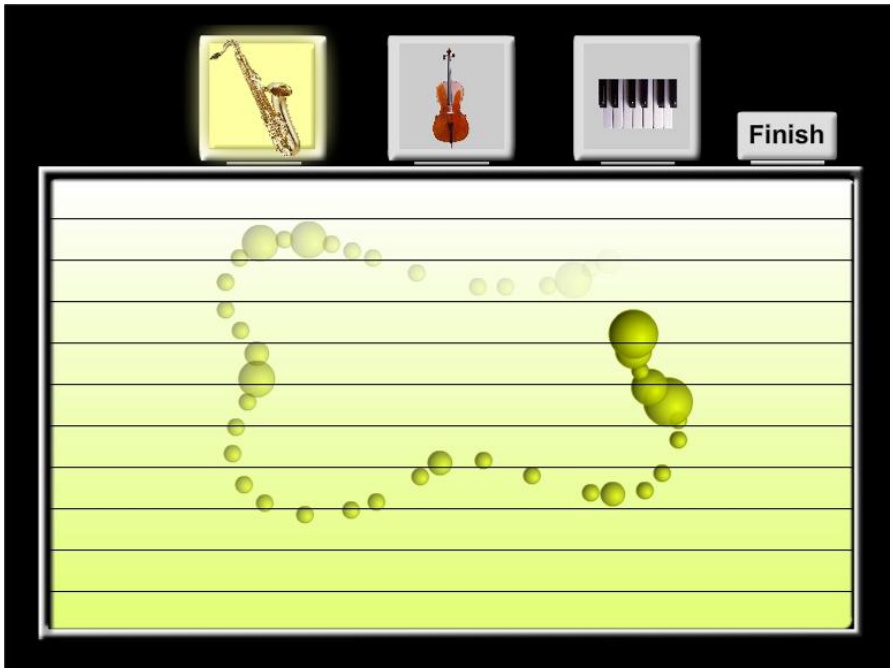

Fig. 3. The ExPress Play interface showing the 'bubble trail' left as the user drags their finger across the screen, creating music.

Users of the system all produced unique musical output. The tracking data showed that each person had a completely individual pattern of use of the system. The different trails of finger movement clearly showed some individuals favouring staccato dabs at points in a row, some making points all over the screen, others opting for continuous lines horizontally, vertically diagonally, or in swoops. None of the participants played in the same way as the others. The project thus fulfilled its aim of assisting the users to be creative in an engaging and satisfying way.

3 Conclusion

There are a number of interesting general findings from this work which may have a more general application to future attempts to provide effective cognitive prostheses.

3.1 Methodology

All of the projects involved potential users throughout the design process, as difficult as this is given the nature of dementia. In some cases novel methods of measuring the effectiveness of the prototypes were developed [17]. The projects all were multidisciplinary in their approach. Given the complex nature of cognitive deficits and their effect on everyday life, this is an important feature to ensure that the results of the work are usable and desirable for intended beneficiaries.

3.2 Hardware

Recent work in this field has moved away from sensors which require to be carried by or attached to the person, and instead rely on using sophisticated computer vision algorithms and to track users' movements and to analyse the behaviour being observed [10,12,13].

3.3 Human Computer Interaction

Systems which require human-computer interaction for people with dementia need be sure it is always obvious to the user what to do next, either because of the way the interface behaves, or because of a specific prompt [23]. It is important, because of the working (short-term) memory problems to provide users with continual feedback [23]. It may be possible to devise ways having a simple stylised visual representation of short-term memory, such as in the music making system [24]. Efforts should be made when using prompt either to have them obvious in their intent, or familiar in design. Unobvious novel prompts are likely to fail [10]. With good design, however, even novel technologies can be introduced, if it is obvious how to use them [14,20,23,24]. Interestingly, even cognitively impaired patients will develop creative unanticipated uses for systems designed for another purpose, and such creativity is to be encouraged [9].

3.4 Impact on Users

Improving the ability of people with cognitive deficits to function better will have a positive effect on staff attitudes towards the people they work with that continues beyond any particular activity session [19]. Ultimately such systems can contribute to ambitious goal of restoring the 'personhood' of the individual with dementia [21,22].

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